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# Exploiting MIMO Vertical Diversity in a 3D Vehicular Environment

Jayashree Thota, Reham Almesaeed, Angela Doufexi, Simon Armour and Andrew R. Nix

Communication Systems & Networks Group, Department of Electrical and Electronic Engineering  
University of Bristol, Bristol, United Kingdom

Email: { [jaya.thota](mailto:jaya.thota@bristol.ac.uk), [Reham.Almesaeed](mailto:Reham.Almesaeed@bristol.ac.uk), [A.Doufexi](mailto:A.Doufexi@bristol.ac.uk), [S.Armour](mailto:S.Armour@bristol.ac.uk), [Andy.Nix](mailto:Andy.Nix@bristol.ac.uk) }@bristol.ac.uk

**Abstract**— Recently there has been strong interest in extending the MIMO processing from the azimuth dimension to include the elevation plane. This paper compares vertically and horizontally oriented dual polar MIMO LTE-A base station antennas pairs, and studies the performance among large set of users and channel predictions. The study also considers a 2D planar MIMO antenna array arrangement which is compared against the horizontal and vertical configuration for a 4x4 MIMO system. In order to study accurately the performance of such 3D MIMO systems, a 3D ITU propagation channel model is employed in addition to the 3D antenna radiation patterns. Bit level simulations are performed for the downlink physical shared channel (PDSCH) in LTE-A operating at 2.6GHz for a vehicle moving at 35kmph in an urban macro environment. The paper examines the best arrangement for LTE base station dual polarised antenna arrays to achieve the lowest spatial correlation values in a MIMO system.

**Keywords**—LTE-A; 3D Ray tracer; 3D/2D channel modelling; SM MIMO, Vehicular Communications

## I. INTRODUCTION

Future Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I) communications will enable a variety of new applications such as Intelligent Transport Systems (ITS), infotainment, e-commerce and location aware services. Standards such as LTE and Dedicated Short Range Communication (DSRC)/802.11p, are proposed for vehicular applications. One technique to improve the spectral efficiency and throughput in such systems is by using Multiple-Input-Multiple-Output (MIMO) antenna diversity. Each standard deploy different antenna configurations at the base station or access point with a range of MIMO modes such as transmit diversity and spatial multiplexing (SM). According to [1], vehicular applications can either use transmit diversity at the cell edge or Single User (SU) MIMO at locations nearer to the base station, and both of them require lower antenna correlation between the dual polarized antenna array pairs [2].

When MIMO techniques are deployed, large capacity gains can be achieved when the sub-channels are spatially decorrelated. However, in a vehicular environment, the promised theoretical gains are not realized due to the significant spatial correlation present in the channel [3] [4]. Thus, a different approach to the positioning and spacing of MIMO antennas is necessary.

Antenna spacing is one factor that affects the MIMO correlation, however, due to space constraints, more compact antennas can translate into reduced site rental costs for

operators. On other hand, the spatial correlation of the MIMO system can be also controlled by different arrangement of antennas. Vertical antenna configuration is one of the configurations that is attracting network operators since it requires less antenna poles and is reducing the mutual coupling between antennas and improving the performance of the antenna radiation patterns [14]. In this context, the vertical or the 2D planar 4x4 MIMO configuration may be more attractive than the horizontal for some sites, as it has a smaller footprint and is better suited to being mounted on pole-like structures [2]. Therefore, this study considers different MIMO arrangement modes with different antenna spacing and proposes the best deployment options for an LTE-A system in an urban vehicular environment.

In order to study accurately the performance of such 3D MIMO systems, a 3D propagation model is required in addition to 3D antenna radiation patterns. The assumption of 2D propagation (in azimuth plane only) breaks down in some environments where the elevation angle distribution is significant. In such cases, the 2D propagation may lead to imprecise estimation of channel capacity and system level performance [5].

To the best of the author's knowledge, there are no existing studies in the literature that predict the 4x4 MIMO performance, with base station antenna arrays in vertical and planar arrangement for LTE-A in a high speed vehicular environment. In previous studies [2], the authors explore the 2x2 MIMO LTE antenna arrangement for 2D cellular communications but do not consider a 3D vehicular environment or a 4x4 MIMO planar or linear configuration and do not perform LTE bit level simulations.

The remainder of this paper is organized as follows: The modelling of the wireless channel is presented in Section II. Section III presents system model assumed for the simulations. Section IV presents the simulation results and analysis is followed by conclusions.

## II. MODELLING OF THE 3D WIRELESS CHANNEL

For our study of vertically and horizontally oriented pairs of dual polarized arrays, we require the deployment of a 3D channel model to accurately evaluate the MIMO performance. The implemented 3D channel model is developed and published as an open source code through the website: <http://enhanced-3d-itu-channel-model.sourceforge.net>. The source code is the enhanced 2D 3GPP/ITU channel model

[6] by extending the channel Large Scale Parameters (LSPs) using data from a validated 3D ray tracer engine [7]. Our 3D channel modeling implementation considers propagation in the azimuth and elevation planes based on point-to-point predictions from each base-station to every UE location for each site-specific urban database. An isotropic antenna was deployed during the channel prediction stage in order to provide a generic channel model that is decoupled from the base-station and UE antenna system. During the latter system level study, any type of transmit and receive antenna pattern (or patterns) can be applied as a spatial-phase-polarization convolution process. Furthermore, we propose new models for path-loss, azimuth angle spread, Root Mean Square (RMS) delay spread and many other LSP related statistics. Models for the de-correlation distance and the cross-correlation of the LSPs are also provided in the published code. The enhanced parts of our model focus on the generation of angle spread statistics and the calculation of the mean ( $\mu$ ) and standard deviation ( $\sigma$ ) of the log of all the LSPs. Readers may also refer to [8] for a more detailed description of the best-fit lognormal channel statistics for macro and micro cell environments as well as the ray tracing related parameters. The published statistics were obtained by averaging all the channel predictions generated from our ray tracer for London and Bristol macro and micro cellular environments. Parameters were also at 800MHz, 2.4GHz and 5.9GHz. The modeled LSPs are the RMS delay spread (RMS DS), the RMS angular spread of the departure azimuth angles, arrival azimuth angles, departure elevation angles and arrival elevation angles (referred to as ASD, ASA, ESD and ESA respectively). We have also provided detailed modeling of the cross-correlation of the LSPs including elevation angles and the de-correlation distances for these parameters. The cross correlation between the LSPs represent the inter-dependence of these parameters, which eventually results in more accurate modeling of these parameters, especially in multi-link environments. The correlation distance represents the maximum UE displacement that causes the LSPs to remain highly correlated [9].

In this study, this channel model is used to generate the channel realizations of the multi-link system described in section III. To ensure a fair comparison study between the different MIMO arrangements, the same set of LS (Large Scale) and SS (Small Scale) parameters is used for each scenario.

### III. SYSTEM MODEL

This section presents the system model related parameters assumed. For the transmitter, a realistic dual polarized LTE-A base station antenna array ( $10^0$  down-tilted, directional with directivity 13 dBi) was considered, while at the receiver, an omnidirectional antenna was deployed. This receiver antenna emulates the case of a receiving antenna mounted on the rooftop of a vehicle. These radiation patterns were measured in an anechoic chamber at the University of Bristol. All patterns are 3D and include full phase and polarization information. The total power radiation patterns are shown in Fig.1 and the antenna parameters in Table I.

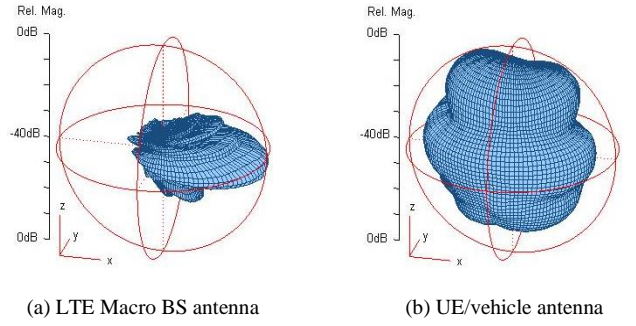


Figure 1: Total measured radiation power.

TABLE I  
3D ANTENNA PATTERN PARAMETERS

Parameter		Value
BS Antenna Type		Uniform linear array with 6 dual polarised patches
UE Antenna Type		Mobile phone antenna (omni-directional)
Antenna 3dB Azimuth/Elevation Beamwidth	BS	65°/15°
	UE	360°/36°
BS antenna downtilt		10°

The paper assumes a macro-cell of 1km radius, where the simulation results are based on 100 random network realizations; each with 100 UEs distributed uniformly in the considered area at random angles from the BS. The simulation is performed for different orientations and spacing of two and four BS antenna arrays as described below:

1. **2x2 MIMO:** Two BS antenna arrays are placed in  $\mathbf{x}$  (horizontal) and  $\mathbf{z}$  (vertical) configurations with antenna array spacing of  $4\lambda$ ,  $10\lambda$  and  $20\lambda$  as shown in Fig.2. Two UE/vehicle antenna elements are placed linearly in the  $\mathbf{x}$  (horizontal) configuration.
2. **4x4 MIMO:** Four BS antenna arrays are placed in  $\mathbf{x}$  (horizontal),  $\mathbf{z}$  (vertical) and  $\mathbf{xz}$  (planar) configurations as shown in Fig6. Four UE/vehicle antenna elements are placed linearly in the  $\mathbf{x}$  (horizontal) configuration.

The MIMO performance is measured in terms of the base station correlation and Packet Error Rate (PER) to determine the impact of the elevation dimension. The 3GPP technical specification of LTE-Advanced [10] defines the Tx and Rx spatial matrices in terms of  $\alpha$  (BS spatial correlation parameter) and  $\beta$  (UE spatial correlation parameter) as shown in (1) and the overall downlink spatial correlation matrix is shown in (2) [11] [12]. It also states a value of  $\alpha=0.3$  and  $\beta=0.9$  for medium correlation,  $\alpha=0$  and  $\beta=0$  for low correlation and  $\alpha=0.9$  and  $\beta=0.9$  for high correlation. Our main goal is to reduce these  $\alpha$  and  $\beta$  correlation values by rearranging the BS antenna arrays in different ways.

$$R_{eNB} = \begin{pmatrix} 1 & \alpha \\ \alpha^* & 1 \end{pmatrix} \quad R_{UE} = \begin{pmatrix} 1 & \beta \\ \beta^* & 1 \end{pmatrix} \quad (1)$$

$$R_{Downlink} = R_{eNB} \otimes R_{UE} \quad (2)$$

Where  $\alpha$  and  $\beta$  can be determined by (3) and (4)

$$\alpha \text{ (BS correlation)} = \langle h_{11}(\tau; t), h_{21}(\tau; t) \rangle \quad (3)$$

$$\beta \text{ (UE correlation)} = \langle h_{12}(\tau; t), h_{22}(\tau; t) \rangle \quad (4)$$

In (3) and (4),  $h_{ij}$  represents the channel matrix for Rx antenna ( $i=1, 2, 3, 4$ ) and Tx antenna ( $j=1, 2, 3, 4$ ) for a 2x2 MIMO configuration. Also, a minimum antenna element separation of  $4\lambda$ , where  $\lambda$  is the wavelength (0.1154m for frequency 2.6 GHz) is recommended in [13].

TABLE II  
LTE SYSTEM PARAMETERS

Parameter	Values
Cell radius	1 km
Bandwidth	10 MHz
BS Transmission Power	43 dBm
Antenna type	Measured pattern
Number of users per cell	100
Number of networks	100
Carrier Frequencies	2.6 GHz (LTE)
BS antenna spacing	$4\lambda, 10\lambda, 20\lambda$
UE antenna spacing	$1\lambda$
Wireless Channel Model	Extended 3D 3GPP/ITU
MIMO scheme	2x2 Spatial Multiplexing (SM)
UE handset type	Vehicle moving at 35kmph in urban macro environment

The 3D statistics in section II are imported directly into the 3GPP/ITU model for generating a set of channel realizations which are then used in the LTE-A PHY bit level simulator. The channel matrices are then normalized and an Additive White Gaussian Noise (AWGN) noise is added to the channel. Table II lists the system parameters, given that a NLOS condition is assumed in this paper. For each Signal to Noise Ratio (SNR) value, 2000 correlated channel realizations according to the Doppler spectrum are carried out for accurate PER analysis. A 2D channel estimation is done based on per sub-frame basis across all subcarriers.

#### IV. RESULTS AND ANALYSIS

We assume a 2x2 MIMO system in subsection A and a 4x4 MIMO system in subsection B followed by an LTE PHY bit level simulation analysis in subsection C. The performance is measured in terms of BS antenna array correlation, where the CDFs of these performance measures are presented for all simulated users and network realizations for NLOS condition.

##### A. 2x2 MIMO case

We compare a pair of dual polarised BS antenna arrays placed in the  $x$  (horizontal) and  $z$  (vertical) orientations with antenna array spacing of  $4\lambda, 10\lambda$  and  $20\lambda$  as shown in Fig 2.

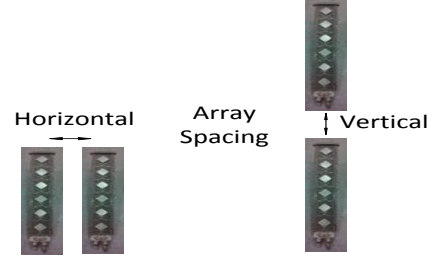


Figure 2: Two Base station Antenna Arrays placed in different orientations

The antenna array spacing has strong impact on the correlation of signals between the two arrays, with wider spacing giving lower correlation [2]. Usually, BS manufacturers have a minimum antenna element separation of  $4\lambda$  with the antennas placed in  $x$  (horizontal) configuration. However if we move the second dual polar antenna array in to  $z$  (vertical) configuration, a decrease in the spatial correlation is observed. Also as the antenna array spacing increases from  $4\lambda$  to  $20\lambda$ , we observe that the difference in correlation between both configurations reduces. This is shown in Fig 3, when comparing  $z@4\lambda$  and  $x@4\lambda$  CDF of the BS correlation graph, where lower correlation is observed in the  $z$  dimension and the difference between  $z@4\lambda$  and  $x@4\lambda$  is higher as compared to  $z@20\lambda$  and  $x@20\lambda$ .

As a 3D ITU channel model is considered, azimuth and elevation spread exists for both the horizontal and vertical orientations. The departure azimuth spread (departure angles are investigated since correlation at BS is considered) is higher than vertical spread for both configurations. This is shown in Fig 4, where the majority of Angle of Departure (AOD) spread in azimuth less than 55 degrees, which is higher than elevation AOD spread in which is mostly less than 5 degrees. Therefore, whether antenna arrays are placed vertically or horizontally, azimuth and elevation spreads do exist at both antenna arrangements, since the same multipath components are received. However, the configuration of the antenna arrays (placed in either horizontal or vertical orientation) will affect the shape of the overall radiation pattern taking into account mutual coupling effect which leads to different spatial filtering of the multipath components.

Thus, the main reason for the lower spatial correlation in the vertical arrangement case (as discussed for Fig. 3) is the lower correlation of the deployed directional antenna array radiations as shown in Fig.5. The figure shows the BS MIMO antenna array field correlation values versus the increase in antenna arrays spacing at steps  $0.1\lambda$  for both antenna array configurations. It shows that when placing the antenna arrays vertically, the cross-correlation of the antenna radiation patterns results in lower correlation which consequently affects the MIMO spatial correlation. In addition, the vertical placement of antenna arrays results in lower mutual coupling as discussed in [14]. The difference in the correlation of the antenna field radiation decreases as the spacing between the antenna arrays increases, which is reflected in the results presented in Fig.3



that shows that that higher antenna array spacing gives lower correlation ( $z@10\lambda$  is better than  $z@4\lambda$ ).

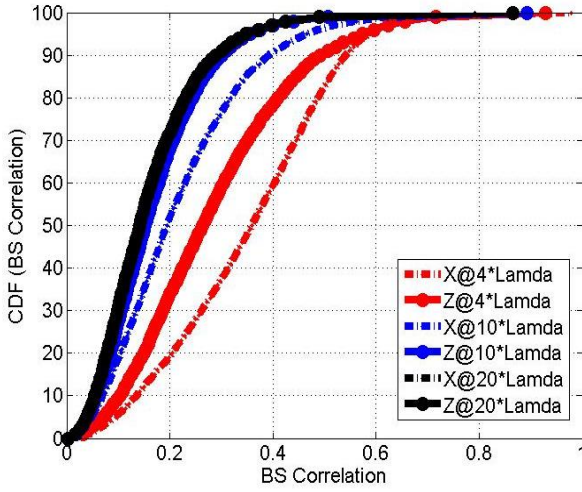


Figure 3: BS antenna correlation CDF for a 2x2 MIMO.

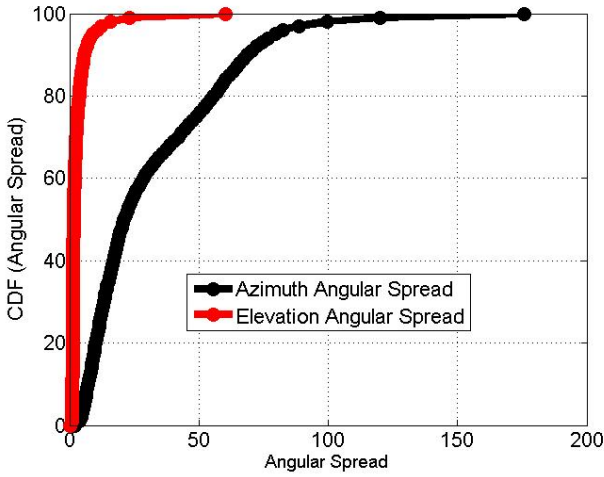


Figure 4: AOD Angular spread CDF for horizontal and vertical configurations

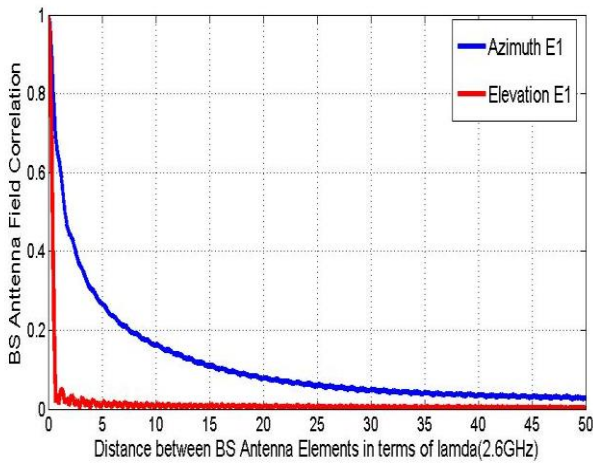


Figure 5: 2x2 MIMO BS Antenna Field Correlation Vs Space in terms of  $\lambda$

### B. 4x4 MIMO case

In this case, we compare four dual polarised BS antenna arrays placed in the  $x$  (horizontal),  $xz$  (2D planar) and  $z$  (vertical), configurations with antenna array spacing of  $4\lambda$  as shown in Fig 6.

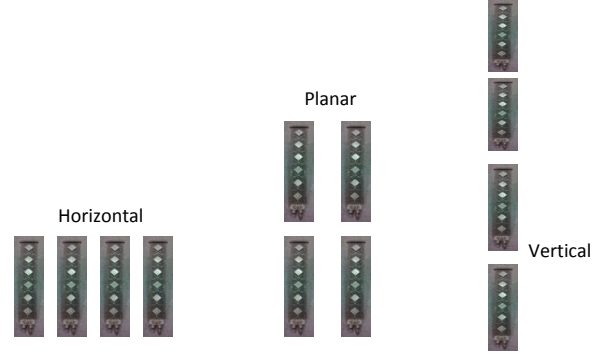


Figure 6: Four Base station Antenna Arrays placed in different orientations

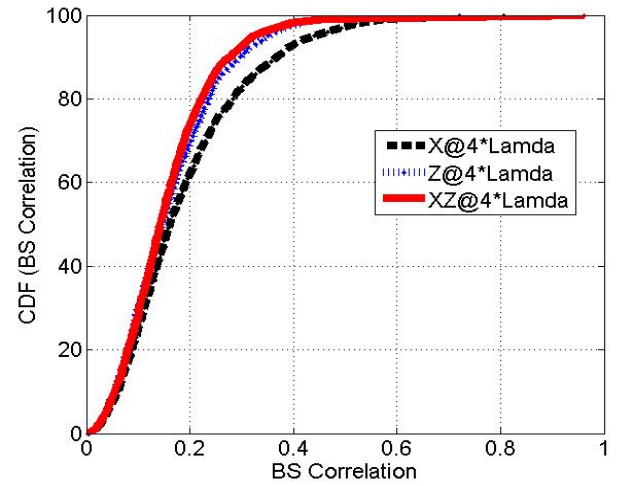


Figure 7: BS antenna correlation CDF for a 4x4 MIMO.

From Fig. 7, we observe that the four antenna arrays placed in the  $xz$  (planar) i.e.  $xz@4\lambda$  and  $z$  (vertical) configuration i.e.  $z@4\lambda$  results in overall lower correlation values at the BS side and thus better performance as compared to antenna arrays placed in  $x$  configuration i.e.  $x@4\lambda$ . Also,  $xz$  (planar) arrangement is only slightly better than  $z$  dimension. However, the 2D planar arrangement has advantages as compared to placing all the antenna arrays linearly. It can save space in a tightly packed urban environment and thus is preferred. Also comparing Fig. 7 and Fig. 3, for  $4\lambda$  spacing, the difference in correlation between vertical  $z@4\lambda$  and horizontal  $x@4\lambda$  arrangement is reduced for 4x4 MIMO. This is because we normally consider correlation between the first and last antenna arrays. For a 2x2 case, the distance was  $4\lambda$  between the pair of antenna arrays, while for the 4x4 case this distance becomes  $12\lambda$  between origin and 4<sup>th</sup> antenna array for the vertical configuration and  $5.6\lambda$  for the planar configuration. It's interesting that in the planar case, although the spacing is lower compared to the vertical case, the planar still gives slightly

lower correlation mostly due to the lower correlation of the fourth antenna elements in the planar arrangement which is shifted in both  $x$  and  $z$  planes, resulting in lower correlation between antenna field radiations. Thus, for a 4x4 MIMO configuration, a 2D planar antenna array arrangement is recommended if operators do not prefer the pole like structure in a vertical dimension.

### C. LTE PHY bit level simulation

The LTE PHY bit level simulation has been performed for a single location and for various MCS schemes to evaluate the performance gain in terms of SNR by using the vertical configuration for a 2x2 MIMO. The assumption of BS antenna array spacing here is  $10\lambda$  and UE antenna of  $0.5\lambda$ . BS antennas arrays are placed either in  $x$  or  $z$  domain and the UE antennas are placed in  $x$  domain.

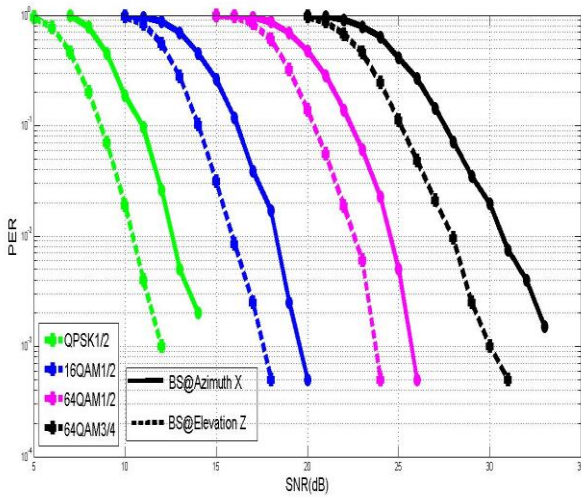


Figure 8: LTE PHY bit level simulations for 2x2 MIMO in Azimuth and Elevation dimensions.

In Fig. 8, we can observe that antennas placed in the horizontal configuration have higher PER for a given MCS. We also observed that to achieve Packet Error Rate=0.01 ( $PER < 1\%$ ), an additional 3dB SNR is required for all MCS modes if antennas are placed in the traditional approach in the horizontal ( $x$ ) configuration. This is due to the lower spatial correlation resulted from placing the antenna arrays in the vertical ( $z$ ) configuration.

### V. CONCLUSIONS

The paper considered the effect of the 3D component on MIMO correlation for different BS antenna arrays configurations. A stochastic 3GPP/ITU 3D channel model is employed for an accurate evaluation of the MIMO performance. The paper recommended the best BS antenna array arrangements to achieve the lowest MIMO spatial correlation when exploiting the elevation plane. We conclude that, in the case of 2x2 MIMO, BS antenna arrays placed in the vertical dimension would be a good choice to implement as this gives lower MIMO spatial correlation and a gain of around 3dB SNR in an urban vehicular macro environment as compared to

the horizontal configuration. For the case of a 4x4 MIMO system, we observed that the deployment of BS 2D planar antenna arrays or BS antenna arrays in vertical arrangement results in overall lower correlation and better performance compared to the horizontal arrangement. A BS 2D planar antenna array arrangement is recommended in the 4x4 MIMO case.

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